Lasers in Surgery and Medicine 26:398–404 (2000)

Pulsed Nd:YAG Laser Irradiation of the Tooth Pulp in the Cat: I. Effect of Spot Lasing

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Background and Objective: **The purpose of the present study was to evaluate physiologically pulpal nerve responses and to elucidate histopathologically the pulp tissue reactions to "spot irradiation" with a pulsed Nd:YAG laser.**
Study Design/Materials and Methods: **Antidromic compound action potentials and the pulpal blood flow (PBF) were recorded from the canine tooth of a sodium pentobarbitone-anesthetized cat. The laser irradiation-induced pulp tissue changes were histologically investigated.**
Results: **The coronal antidromic compound action potentials disappeared in all the teeth tested during lasing, and the time needed to erase them was significantly shortened with increases in lasing power ($P < 0.05$). The radicular PBF increased when spot irradiation was performed, and the coronal PBF also temporarily increased with low-powered lasing. Histologic investigation revealed that spot irradiation with the laser produced severe damage in the pulp tissue in a dose-dependent manner.**
Conclusion: **The present study suggests that spot irradiation with a pulsed Nd:YAG laser risks producing nerve injury and irreversible tissue damage in the pulp with lasing for the purpose of desensitizing hypersensitive dentin. Lasers Surg. Med. 26:398–404, 2000**

Key words: antidromic compound action potential; hypersensitive dentin; nerve injury; pulpal blood flow; pulpal tissue damage

INTRODUCTION

The laser has been used in various fields of basic and applied science. In the medical field, so-called "soft lasers" such as He-Ne lasers or semiconductor diode lasers have been used to reduce patients' pain [1,2]; in dental clinics, these lasers have started to be applied in the treatment of dental hypersensitivity. "Hard lasers" have also been used for various purposes in dental medicine [3]. Irradiation with a pulsed Nd:YAG laser has also been reported to reduce the sensitivity of dentin or to desensitize the pulp nerve and has been used in dental clinics for the purpose of reducing dentin hypersensitivity [4,5]. Whitters et al. showed that pulsed Nd:YAG laser irradiation produced a small, but statistically significant, increase in the threshold of pain perception with electrical stimulation of healthy tooth pulp [6]. However, the basic mechanisms of the above-mentioned intrapulpal nerve desensitizing phenomena have not been clarified, and pulp tissue irradiation caused by lasing has not been discussed. Some investigators have shown that functional changes, as well as morphologic changes, in the dental pulp tissue occurred after irradiating with a hard laser [7–9]. However, there are no reports combining studies of both functional

Contract grant sponsor: Ministry of Education, Science, Sports, and Culture, Japan; Contract grant number: 05404065; Contract grant number: 06671903; Contract grant number: 10470403.

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Accepted 10 December 1999

TABLE 1. Variable for Spot Irradiation With the Pulsed Nd:YAG Laser Used in the Present Study

Irradiation power (W)	Pulse frequency (pps)	Energy per pulse (mJ/pulse)	Power (W/cm^2)	Number of cases (n)
0.6	10	60	75	7
1.0	10	100	124	7
1.5	15	100	187	11
2.0	20	100	249	8
3.0	30	100	373	6

changes in intrapulpal nerves and pulpal blood flow (PBF) and on morphologic changes in pulp tissues after pulsed Nd:YAG laser irradiation. Furthermore, there is no recommendation for pulsed Nd:YAG laser irradiating conditions for desensitizing the pulpal nerve while maintaining normal blood flow in the pulp. Thus, the present study was aimed not only to examine the changes in intrapulpal nerve activity, but also to investigate histopathologic changes in the pulp tissue with pulsed Nd:YAG laser irradiation of the pulp through the normal dental hard tissue in the cat. Preliminary data have been published in a previous abstract [10].

MATERIALS AND METHODS

General Preparations

All of the experiments in the present study conformed to the regulations of the Tokyo Medical and Dental University Animal Care Committee. A total of 25 adult cats (each weighing 2.4–5.4 kg) with intact permanent canine teeth were anesthetized with sodium pentobarbitone (50 mg/kg, i.p.) and used in physiologic and histologic experiments. The animals' functions such as heart rate, arterial blood pressure, respiratory rate, expired P_{CO_2}, and body core temperature were continuously monitored throughout the whole experiment and were kept in the physiologically normal range: R–R interval: 250–350 ms, 100–140 mmHg, 30–35 per minute, 3.5–5.5%, and 35.5–37.0°C, respectively.

Laser Irradiation Styles

A lasing machine with a pulsed Nd:YAG laser (wavelength: 1,064 nm) (dLase300, American Dental Laser) was used in this experiment as the source of laser irradiation. The pulsed Nd:YAG laser was applied to the canine tooth with the irradiating conditions as shown in Table 1. It was irradiated at one point of the cervical portion of the crown with a tip of the lasing probe 0.1–0.2 mm away from the tooth surface attached to a micro-manipulator; that is, the laser was applied with a pulse width of 150 μs guided through the optical fiber (diameter: 320 μm) with 60–100 mJ/pulse energy (Table 1). The position of the laser probe was monitored with a He-Ne aiming beam (1.0 mW He–Ne laser), which always accompanied Nd:YAG irradiation.

Physiologic Investigations

The effect of the pulsed Nd:YAG laser on intrapulpal nerve activity. The responsiveness of the intrapulpal nerve fibers was examined to determine sites affected by irradiation with the pulsed Nd:YAG laser. A total of 39 canine teeth were prepared for this examination; that is, periodontal tissues, including the alveolar bone around the canine root of the buccal surface, were surgically removed. Dentinal electrodes for recording intrapulpal nerve activities as antidromic compound action potentials (ACAP) were made on the canine (Fig. 1); that is, four dentinal small cavities were prepared on the canine in which fine silver wires were fixed with an Ag/AgCl mixture. These electrodes were accompanied by an Ag/AgCl electrode in the acrylic cap attached to the tip of the canine. While the pulsed Nd:YAG laser was applied to the cervical portion of the canine, the ACAP of the intrapulpal nerves were recorded for 5 minutes with dentin electrodes at the following four positions in each canine: the coronal third (R_1) and middle third (R_2) of the crown, and the cervical third (R_3) and middle third (R_4) of the root (Fig. 1). The intensity of the electrical stimulation to the inferior alveolar nerve bundle or to the infraorbital nerve was kept at 1.5 times the power of the threshold, by which the maximal response was always evoked as in the ACAP, and recorded through these electrodes. Once any of the recorded ACAP became undetectable on the monitoring oscilloscope during laser irradiation, the lasing was immediately stopped. When the ACAP recovered to 10% of the preapplication level during monitoring for 30 minutes after lasing, the same lasing was repeated three times at the maximum level.

Pulpal blood flow changes during lasing. The PBF of the canine was also recorded at the coronal and radicular portions by means of the laser Doppler flowmetry method (PeriFlux PF3, Perimed, Sweden) simultaneously with intrapulpal nerve response recordings upon irradiating with the pulsed Nd:YAG laser (Fig. 1). We tried to determine the safe irradiation conditions

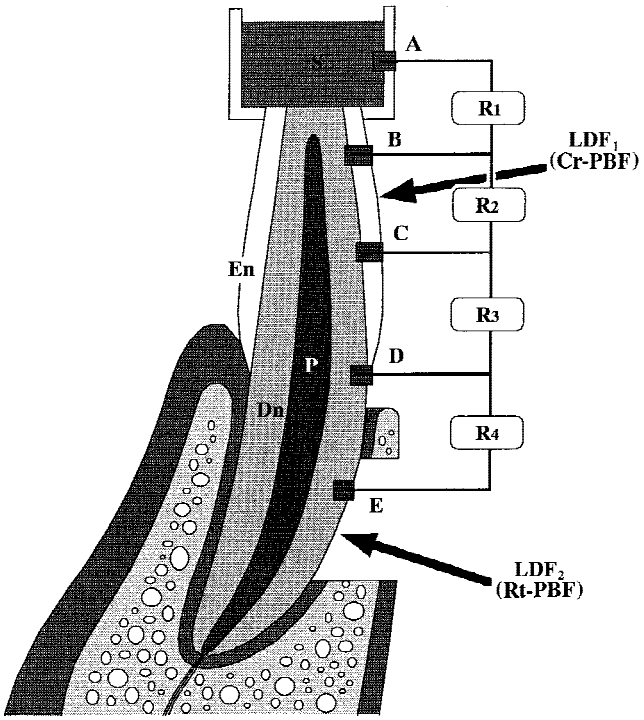

Fig. 1. Schematic drawing of the recording method for antidromic compound action potentials (ACAP) in the cat canine tooth. Electrical stimulation (duration, 0.1 ms; frequency, 1 Hz) was applied to the nerve bundle innervating the canine at the appropriate intensity, and the ACAP R_n was recorded. Spot irradiation with the pulsed Nd:YAG laser was performed on the labial surface of the canine crown between electrodes C and D. Coronal and radicular pulpal blood flow were recorded by using the laser Doppler flowmetry method (LDF_1 and LDF_2, respectively). A, B, C, D, and E, Ag/AgCl electrode; S, physiologically normal saline; En, enamel; Dn, dentin; P, tooth pulp. Cr-PBF, coronal pulpal flow; Rt-PBF, root pulpal blood flow.

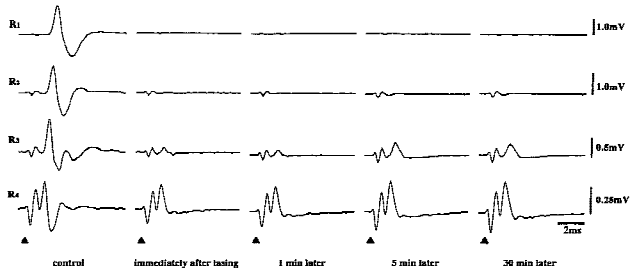

Fig. 2. An example of the changes in the antidromic compound action potentials (ACAP) before and after spot irradiation with the pulsed Nd:YAG laser. The ACAP R_1, R_2, and R_3 decreased in amplitude immediately after lasing and did not re-appear completely even 30 minutes after lasing. In particular, the action potential R_1 could not be recorded for several minutes. The ACAP R_4 was not affected by laser irradiation. Lasing conditions: power, 1.5 W; frequency, 15 pps; and lasing time, 46 seconds. Triangles indicate electrical stimulation artifact.

for using pulsed Nd:YAG laser on the canine pulp; that is, the appropriate lasing conditions were assessed by detecting the power and energy of faint recordings of intrapulpal nerve activity while maintaining normal pulpal blood flow.

Histologic investigation. All of the tooth specimens irradiated by the Nd:YAG laser were histologically examined for tissue reactions caused by lasing. The tooth specimens were dissected out at the termination of the physiologic experiments after perfusion fixation was performed with 10% neutral formalin solution. After further fixation for 1 week, the specimens were decalcified in ethylenediaminetetraacetic acid solution, embedded in paraffin, sectioned sequentially (thickness: 5 μm), and stained with hematoxylin and eosin. The criteria for histopathologically evaluating the specimens under a microscope were as follows: changes in the odontoblastic layer (disarrangement, degeneration, or disappearance); hemorrhage into the pulp tissue; and damage, degeneration, or necrosis sustained by the pulp tissue.

RESULTS

Changes in ACAP Recorded From Dentin Electrodes and PBF With "Spot Lasing"

The ACAP R_1 and R_2 almost simultaneously disappeared in all teeth tested by "spot lasing" (Fig. 2). The total lasing time until the disappearance of R_1 significantly reduced with increases in the lasing power (Spearman rank correlation test, $P < 0.05$) (Fig. 3). After finishing the first spot irradiation with the pulsed Nd:YAG laser, the ACAP of R_1 or R_2, once it disappeared, was sometimes re-observed within a minute. There was a higher probability of the reactivation of the ACAP, and a larger amplitude of the rekindled potentials, being observed in cases for which weaker power was used in irradiating with pulsed Nd:YAG laser.

As for the PBF, the increase was observed in both the coronal and root portions when "spot lasing" was performed, except with the higher power lasing (Fig. 4a). When higher power lasing was applied to the crown, no increase in coronal PBF was observed or, rather, the PBF could not be measured by the laser Doppler flowmeter (Fig. 4b). Furthermore, the ACAP of R_1 and R_2 were barely observed and did not return to the prelasing control level, even half an hour later after lasing in any tooth in which the coronal PBF was significantly decreased by "spot lasing."

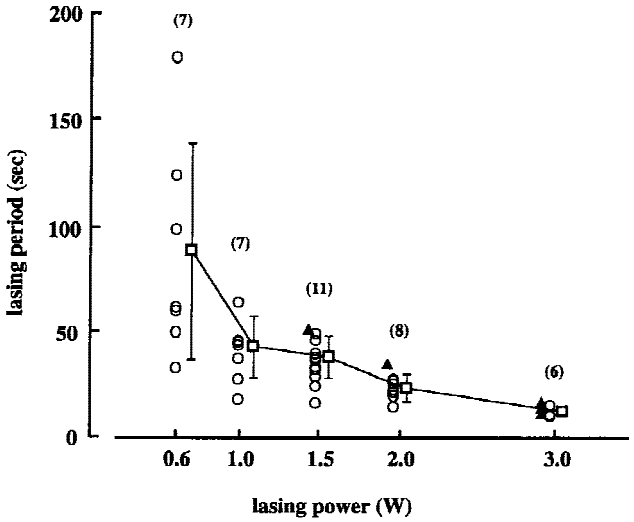

Fig. 3. The relationship between spot-irradiation power and irradiation time until the antidromic compound action potential R_1 disappeared. The total irradiation time until the disappearance of R_1 significantly decreased with an increase in lasing power (Spearman rank correlation, $P < 0.05$). Circles indicate a tooth in which coronal blood flow was maintained; triangles indicate a tooth in which coronal blood flow was not detected with laser Doppler flowmetry; squares indicate mean, and error bars indicate SD.

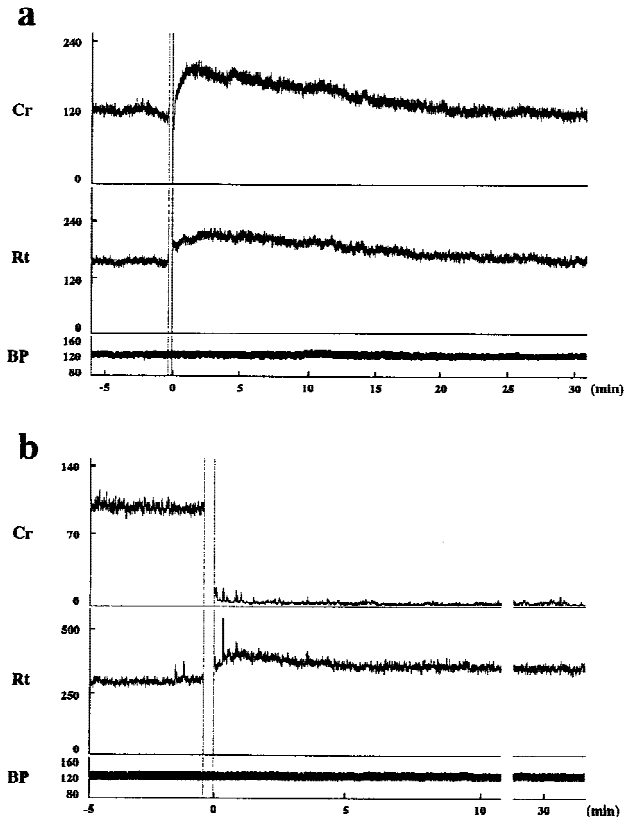

Fig. 4. Two examples of changes in the pulpal blood flow (PBF) before and after spot irradiation with the pulsed Nd:YAG laser. **a:** Both the coronal and radicular PBF temporarily increased immediately after lasing and then decreased to the baseline level. Lasing conditions: power, 0.6 W; frequency, 10 pps; irradiation time, 34 seconds. **b:** Coronal PBF could not be detected immediately after lasing, and the radicular PBF temporarily increased after lasing and then decreased to the baseline level. Lasing conditions: power, 2.0 W; frequency, 20 pps; irradiation time, 35 seconds. Cr, coronal PBF (mV); Rt, radicular PBF (mV); BP, arterial blood pressure; and line, spot irradiation with the pulsed Nd:YAG laser.

The Alteration of the Pulp Tissue With the Pulsed Nd:YAG Laser Irradiation

In the tooth specimens irradiated with "spot lasing," the histopathologic changes in the pulp tissue were observed mainly just beneath the laser-irradiated portion of the dental hard tissue. Even in the tooth pulp, irradiated with the pulsed Nd:YAG laser with the weakest power of 0.6 W, the alterations in the pulp tissue such as the disarrangement of the odontoblast layer and vasodilatation were observed. Higher powered lasing with 1.5 W produced more severe damage in the pulp tissue; that is, the pulp was degenerated and, in some cases, necrotized. The local pulp tissue just beneath the dentinal tubules through which the laser energy was transmitted was totally destroyed by much higher power of 2.0 or 3.0 W spot lasing (Fig. 5).

DISCUSSION

In the present study, we first demonstrated that pulsed Nd:YAG laser irradiation of the cat canine tooth pulp through the intact dental hard tissue could reduce the amplitude of ACAP recorded in the coronal part of the canine where the lasing energy was directly focused. In addition, lasing increased the PBF both in the coronal and root pulp with low-powered lasing, and also induced histopathologic changes in the pulp tissues. Some investigators reported that laser irradiation, by using the same model of machine used in this experiment, of extracted human teeth significantly increased the temperature in the pulp chamber [11,12]. It was reported that the application of thermal stimuli (either hot or cold) to the tooth pulp produced an increase in intrapulpal nerve activities [13,14] and also that, in humans, the perception of pulpal pain increased as a function of intradental nerve activity [15]. However, there is also a report that the exposure of nerve fibers to a high temperature environment decreased the amplitude of compound action poten-

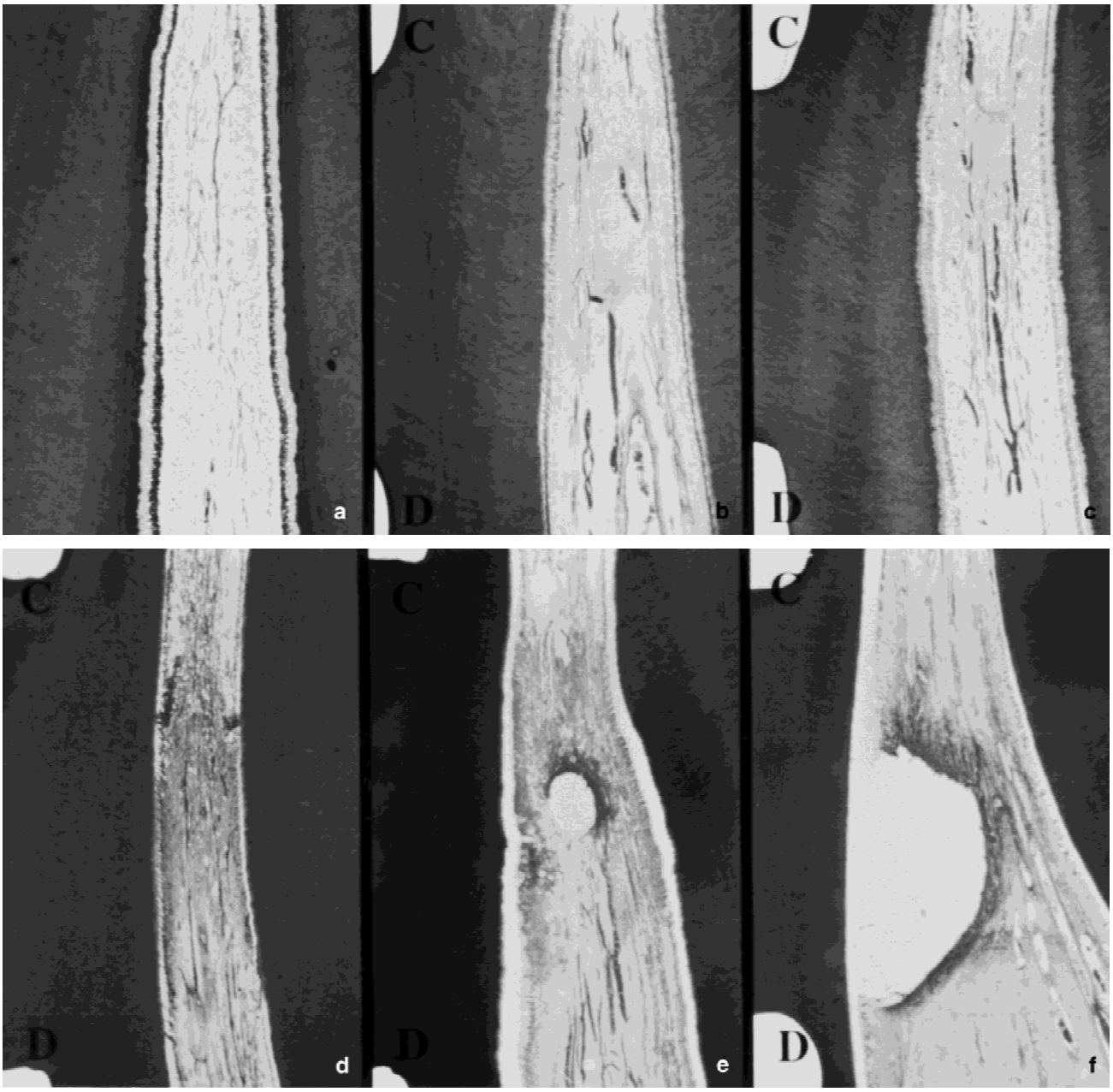

Fig. 5. Photomicrographs of a series of histopathologic changes in the pulp tissue caused by spot irradiation with the pulsed Nd:YAG laser. Note that severe damage to the tooth pulp was produced in a dose-dependent manner and that there was no significant histologic change in the dental hard tissue. **a:** Nonirradiation group (control) (original magnification, ×250). **b:** Spot irradiation group with 0.6 W, 98 seconds (original magnification, ×250). **c:** Spot irradiation with 1.0 W, 48 seconds (original magnification, ×250). **d:** Spot irradiation with 1.5 W, 37 seconds (original magnification, ×250). **e:** Spot irradiation with 2.0 W, 25 seconds (original magnification, ×60). **f:** Spot irradiation with 3.0 W, 14 seconds (original magnification, ×60). C and D, cavities for electrodes (see Fig. 1).

tials evoked in them in a short time [16,17]. However, the increase in the pulp temperature produced pathologic changes in the pulp tissue [18,19], even though there is still an unclarified reason why laser irradiation can decrease intrapulpal nerve activities observed as ACAP in this study. The severe pathologic changes in the pulp tissue caused by lasing may be induced mainly by thermal effects produced by irradiation with the pulsed Nd:YAG laser.

The possible mechanisms of the above-mentioned nerve and tissue reactions to pulsed

Nd:YAG laser irradiation may be explained as follows. The sensitivity of the dental hard tissue and dental soft tissue such as tooth pulp to the pulsed Nd:YAG laser differed from each other. The Nd:YAG laser could easily penetrate the dental hard tissue [20] and was absorbed into the hemoglobin in the red blood cells, where the laser energy can be transferred into heat energy. However, dental hard tissues such as enamel and dentin have adiabator properties and can usually protect the pulp inside from external high-temperature thermal stimuli [18]. It is easily speculated that adiabatic dental hard tissue may accumulate the heat inside the pulp, which then produces heat-related damage in the pulp tissue. The anatomically specific structures of the tooth and the heat-accumulating capacity of enamel and dentin may also produce temperature increases in the pulp.

It has been reported that in the pulp there are arteriovenous anastomoses, and that shunting was more prevalent in the apical half than the coronal half of the pulp [21]. The changes in pulpal blood flow were induced when inflammatory change or damages to the pulp tissue occurred in the pulp [22,23]. The pulpal blood vessels showed morphologic changes during acute inflammation; the first stage of inflammation increases the vascular permeability and occurs primarily in the venous system [23]. The present study clearly demonstrated that the blood flow of the coronal pulp decreased and that of the root pulp increased when severe tissue damage was produced in the coronal pulp by pulsed Nd:YAG laser irradiation (Figs. 4a,b, 5). However, the decreased amplitude in the ACAP recorded from the coronal part of the tooth (R_1 and R_2) were not detected in teeth whose coronal blood flow could not be measured by the laser Doppler flowmeter. This fact suggests that the activity of pulpal nerve fibers may deteriorate due to the anoxia condition associated with pulpal ischemia [24,25].

In conclusion, spot irradiation with a pulsed Nd:YAG laser to the pulp has a high potential to damage the pulp tissue. It should be emphasized that the clinical application of this laser to dental treatment for the purpose of desensitizing the dentin, or for an anesthetizing effect on the tooth pulp, risks severely damaging the pulp tissue. Further studies are needed on the clinical applications of this kind of laser to determine the most suitable conditions that avoid damaging the pulp tissue.

ACKNOWLEDGMENTS

H.S. and M.S. were supported in part by a Grant-in-Aid for Scientific Research from the Ministry of Education, Science, Sports, and Culture, Japan.

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